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Autonomous Response to Unexpected Events in DoD Terminal Operations (ARTUE-DTO) Concluding Report

27 September 2013

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14. ABSTRACT
Autonomous Response to Unexpected Events for Defense Terminal Operations (ARTUE-DTO) (R2D2) is a Research, Development, Test, and Evaluation project sponsored by the United States Transportation Command. The introduction of service-oriented computing and Radio Frequency Identification (RFID) technologies present opportunities to realize substantial improvements in the efficiency, response time, and throughput of transportation operations, while minimizing the unintended consequences of unplanned actions prompted by unexpected events. Realizing the benefits of these technologies requires the creation of intelligent services with advanced reasoning capabilities. R2D2 is proposed to improve plan de-confliction and re-planning within the ICODES Single Load Planner (SLP) and Terminal Management Module (TMM) domains through the application of ARTUE reasoning technology that was developed at the Naval Research Laboratory (NRL).

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Executive Summary

This document provides a concluding summary for the ARTUE-DTO project. It includes an Overview of the project, Conclusions, and follow-on Recommendations. A Functional Description of the Dashboard Display and the associated Progress Metrics and Agent Alerts give context for the recommendations. References are provided for project documents containing additional information (e.g., detailed designs and transition plans). Lastly, summary descriptions of late term project investigations are included as attachments.

1 Overview

Autonomous Response to Unexpected Events for Defense Terminal Operations (ARTUE-DTO) (R2D2) is a Research, Development, Test, and Evaluation project sponsored by the United States Transportation Command. The introduction of service-oriented computing and Radio Frequency Identification (RFID) technologies present opportunities to realize substantial improvements in the efficiency, response time, and throughput of transportation operations, while minimizing the unintended consequences of unplanned actions prompted by unexpected events. Realizing the benefits of these technologies requires the creation of intelligent services with advanced reasoning capabilities. R2D2 is proposed to improve plan de-confliction and re-planning within the ICODES Single Load Planner (SLP) and Terminal Management Module (TMM) domains through the application of ARTUE reasoning technology that was developed at the Naval Research Laboratory (NRL).

R2D2 operates above individual planning and execution systems to provide an overarching perspective of the interdependent load planning activities occurring across the transportation network. The plans at a given node have dependencies on the plans at other nodes. Significant changes in the information from which a plan was derived may occur during planning, and significant deviations from the planned state may arise during execution. These planning problems propagate across the transportation network, compounding their operational impact. R2D2 automatically monitors evolving plan and execution states in ICODES SLP and TMM to identify planning and execution discrepancies, determine potential impacts, and derive recommendations for corrective actions as appropriate.

The proof-of-concept implementation of the R2D2 Service Oriented Architecture (SOA) design[1] was developed and demonstrated in the context of a load planning scenario that was evolved over the course of the project performance. The final R2D2 demonstration comprises a multi-phased ship pre-stow plan, a corresponding as-loaded plan, and a supporting TMM terminal operations plan linked in a dynamic re-planning collective. As execution progresses, significant discrepancies with the pre-stow plan emerge. The R2D2 Dashboard display implements a Continuous Intelligence paradigm that promptly notifies users of the potential issues through Agent Alerts and characterizing Performance Metrics that are dynamically updated as the operation proceeds. Users accordingly make dynamic adjustments to the Load Plan in SLP or the Operations Plan in TMM as plan execution continues.

[1] See the ARTUE-DTO Technical Design Report for a detailed R2D2 design specification.

2 Conclusions

The following conclusions were derived from the performance of contracted R2D2 project tasks including the development and demonstration of the R2D2 proof-of-concept implementation.

- ***Service Reuse:*** The existing SOA interfaces that were developed for the ICODES Hand Held Terminal (HHT) to interface with TMM and SLP prove useful as general purposed interfaces for the development of new enterprise capabilities (e.g., R2D2) that are external to ICODES but directly compose (i.e., reuse) or collaboratively interact (i.e., interface) with ICODES SLP and/or TMM services.
- ***Domain Independent Rules:*** Relatively simple rules concerning planned and actual cargo type and position in the context of the available space and time can be developed that apply to all load-planning domains (i.e., Air, Ship, Rail, and Yard) and effectively assist human operators in identifying potential planning and execution problem—particularly within complex multi-phased load plans involving many thousands of cargo items.
- ***Linked Load Planning and Terminal Operations:*** R2D2 agent configuration can provide temporal context to the essentially atemporal load plan constructs of ICODES SLP, particularly when used to link SLP load plans to the fully temporal TMM representation of supporting terminal operations.
- ***ARTUE Reasoning Engine:*** The rules implemented for the R2D2 proof-of-concept proved to execute faster using an ICDM-based implementation than using the NRL developed ARTUE reasoning engine. Additionally, the ARTUE engine was found to require specialized uncommon knowledge of the LISP programming language for its rule encodings and maintenance. ARTUE is more applicable to applications with fewer facts (e.g., cargo items) and a large number of complex domain specific rules.
- ***SOA Capability Development and Evaluations:*** The SOA infrastructure and capability stack of ICODES supports the rapid development of new experimental capabilities directly within the computing context of the enterprise; however, availing new services for user trial and evaluation proves more difficult as the they have yet to receive Authority to Operate (ATO) on the Government networks hosting the production system environments and services upon which they are based.

3 Recommendations

As the project concluded, many ideas for what next to explore were conceptualized by the project team. These were consolidated to produce the following recommendations for options to consider for capitalizing the R2D2 technology in follow-on phases.

- ***Experimental Tools Area:*** Consider incorporating an Experimental Tools Area in the ICODES Production Environment for use in RTD&E software evaluation and technology transition purposes. A significant limitation of RTD&E efforts is the ability to avail them to real-world user communities for collaborative development and evaluation in the context of real-world operations. The ICODES SOA platform and Web portal can provide potential users with convenient access to R2D2 capabilities in a controlled and secure manner.

- ***Direct Technology Integration:*** Consider integrating R2D2 technology directly into the ICODES Production Environment. R2D2 technology can be exploited in many different ways by the existing ICODES services and applications. For example, the experimental application of R2D2 technology for container sequencing is perhaps best progressed directly in TMM in the context of current-proposed software change requests (SCRs). The reasoning capabilities of the ARTUE engine can be employed to improve the automatic load planning service utilized by SLP and other ICODES applications as another example.

- ***Cross Terminal Applications:*** Consider using R2D2 technology for the automatic communication of significant load plan changes to follow-on ports so their discharge and pre-stow plans can be accordingly adjusted. For example, when an as-loaded plan representing a ship's manifest is deposited in the ICODES Information Repository, R2D2 can be extended to automatically compare it the prior-deposited pre-stow plans at the shipping and receiving ports and send email notification to the load planning activity at the receiving port if re-planning is advised.

- ***Dynamic Yard Applications:*** Consider R2D2 technology combined with increasingly common RFID solutions for dynamic container placement applications. ARTUE can improve efficiency in new ways. Responsiveness to individual container movements can be provided via tablets or other portable devices; for example, when a container is moved and scanned, R2D2 can be modified to direct the operator to place it atop a stack of long-term containers rather than atop containers that must soon be moved. Every container move saved is efficiency gained. The return is increased as the technology progressively looks farther into the future and considers other impacting factors.

- ***Preposition Shipping Applications:*** Consider applying R2D2 technology to preposition ship loading and container processing problems exemplified by those at the Marine Ocean Terminal at Sunny Point (MOTSU). The need to not only frequently move, but stuff, un-stuff, and re-stuff containers in the context of inspection and refurbishing processes presents an additional layer of complexity upon the domain-independent rules provided by the R2D2 Proof of Concept. In addition to optimally sequencing the stacking and servicing of containers, the goal

to load containers such that any build number is accessible within four (4) lifts can be greatly facilitated by extensions to the container stacking rules R2D2 implements.

4 Functional Description

R2D2 provides users with Continuous Intelligence about the load planning operations that they have configure their R2D2 Agents to monitor for them, including those with interacting terminal and load planning operations occurring within and across globally distributed transportation facilities. It provides visibility of cargo across transportation modes and plan phases with a Dashboard Display that promptly informs users of significant plan deviations through use of Performance Metrics and Agent Alerts that provide plan-change recommendations as appropriate.

4.1 Dashboard Display

The R2D2 Dashboard display of Figure 1 shows the Operational Progress Timeline illustrating an operation involving the offloading of cargo from two ships onto a train in the context of an overarching operation named the Jacksonville Execution. The Cargo Status indicator provides dynamic knowledge of the distribution of actual, planned, unplanned, and unaccounted for cargo. The Progress Metrics and Agent Alerts that are shown along the bottom of the Dashboard display are described in the following subsections.

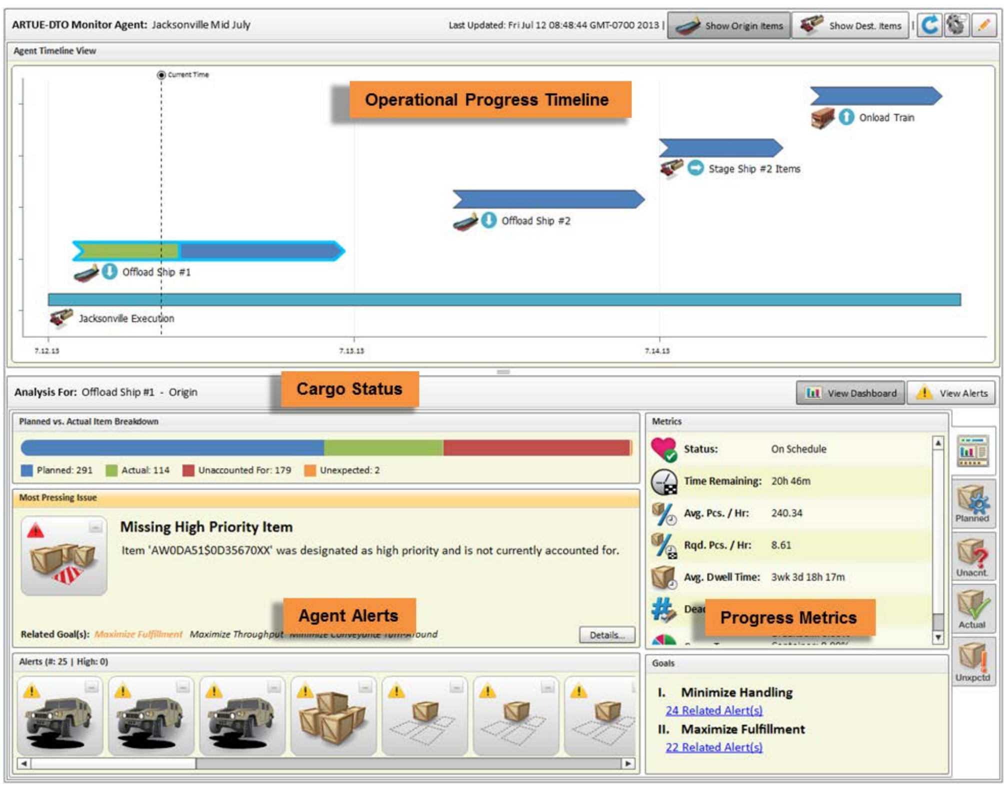

Figure 1: R2D2 Continuous Intelligence Dashboard Display

4.2 Progress Metrics

The R2D2 Dashboard provides configurable displays of the temporal and statistical metrics that the R2D2 agent maintains for characterizing the ongoing progress of transportation operations. Progress Metrics implemented by the R2D2 Proof-of-Concept include the following.

- The ***Status metric*** indicates if the holistic transportation operation is on schedule, behind schedule, or not started.
- The ***Time Remaining metric*** indicates the time remaining until the transportation operation is scheduled to end.
- The ***Avg. Pcs. per Hour metric*** indicates the average number of items that are being moved into their planned locations per hour.
- The ***Rqd. Pcs. per Hour metric*** indicates the average number of items that must be moved into their planned locations per hour to complete the transportation operation by the scheduled completion time.
- The ***Avg. Dwell Time metric*** indicates the average timespan that items are remaining in the same area over the course of the transportation operation.
- The ***Dead-lined Cargo metric*** indicates the currently known number of dead-lined (i.e., inoperable) cargo items that must be accommodated in accomplishing the transportation operation.
- The ***Cargo Types metric*** indicates the percentage breakdown of cargo types (e.g., pallet, vehicle, break-bulk, and container) that are involved in the transportation operation.
- The ***Pcs. Moved Since Last Analysis metric*** indicates the number of items that have been moved since the last time R2D2 performed its analysis.

4.3 Agent Alerts

The R2D2 Dashboard provides configurable displays at various levels of filtered detail for examining the alerts generated by the R2D2 agent to indicate and describe potential planning or execution issues as they emerge. Agent Alerts implemented by the R2D2 Proof-of-Concept include the following.

- The ***Missing High Priority Item alert*** identifies high priority cargo items that are currently unaccounted for.
- The ***Planned Area Over Capacity alert*** identifies conveyance loading areas that are anticipated to be over capacity as a result of several movement operations utilizing the area at the same time.
- The ***Unexpected Dead-lined Item alert*** identifies equipment items that have been unexpectedly discovered to be incapable of self-propelled movement.
- The ***Items Did Not Arrive alert*** identifies cargo items that remain unaccounted for at the planned completion time for the transportation operation.

- The ***Follow-On Movement Impacted alert*** identifies cargo items that remain unaccounted for, but are specifically planned for in a future-dependent transportation operation.
- The ***Unavailable Items alert*** identifies cargo items that are planned for in the context of the transportation operation but did not arrive at their previous destination.
- The ***Too Many Items of NSN in Area alert*** identifies situations in which there are more cargo items of a particular type within a load area than were planned for—as indicated by the National Stock Number (NSN).
- The ***Too Few Items of NSN in Area alert*** identifies situations in which there are less cargo items of a particular type within a load area than were planned for—as indicated by the National Stock Number (NSN).

5 References

The following documentation was produced in the context of the R2D2 research and is available from Tapestry Solutions upon request.

RTD&E Proposal: JDDE RDT&E Project Proposal Autonomous Response to Unexpected Events in DoD Terminal Operations (ARTUE–DTO), 14 May 2010, CDM Technologies, Inc. 2975 McMillan Avenue, Suite 272 San Luis Obispo, CA 93401

Performance Work Statement: ICODES ARTUE-DTO Performance Work Statement Amendment 3, 9 August 2012, Contract No.: HTC711-Q-12-D060

Technical Approach Proposal: Integrated Computerized Deployment System (ICODES) Autonomous Response to Unexpected Events in Department of Defense (DoD) Terminal Operations (ARTUE-DTO) Contract No.: HTC711-Q-12-D0600 Proposal No.: 12-050, 14 August 2012 CDM Technologies, Inc. 2975 McMillan Avenue, Suite 272 San Luis Obispo, CA 93401

System Description and Use Cases: ARTUE-DTO Prototype System Description and Notional Use Cases, Contract No.: HTC711-Q-12-D0600, Deliverable No.: 1.3.2.1.1, 31 October 2012, Tapestry Solutions, Inc. 2975 McMillan Avenue, Suite 272 San Luis Obispo, CA 93401

Transition Plan: ARTUE-DTO Draft Technology Transition Plan, Contract No.: HTC711-Q-12-D0600, Deliverable No.: 1.3.2.3.1, 30 November 2012, Tapestry Solutions, Inc. 2975 McMillan Avenue, Suite 272 San Luis Obispo, CA 93401

Research Report: ARTUE-DTO Research Report, Contract No.: HTC711-Q-12-D0600, Deliverable No.: 1.3.2.2.1, 30 November 2012, Tapestry Solutions, Inc. 2975 McMillan Avenue, Suite 272 San Luis Obispo, CA 93401

Technical Design: ARTUE-DTO Technical Design Report, Deliverable No.: 1.3.2.1.1, 31 January 2013, Tapestry Solutions, Inc. 2975 McMillan Avenue, Suite 272 San Luis Obispo, CA 93401

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Attachment 1: ARTUE Performance Improvements

R2D2 research identified the performance of the NRL ARTUE reasoning engine as a significant issue for near real-time applications such as that illustrated by the R2D2 demonstration scenario and container yard stacking investigation. While several improvements were made to the ARTUE code base to speed up the system two in particular made a significant difference. The first change was to replace the prototype rule engine, used for finding triggered notifications, in favor of a faster third-party alternative based on Prolog. The second change replaced the Java Virtual Machine (JVM)-based execution of cognitive reasoning services with a faster native solution. The results of these improvements, which greatly increased the practicality of generating notifications based on large plans, are shown in Figure 2.

Performance Testing

For the tests shown in Figure 2, randomized operation objects were created and run for four (4) different conditions at ten (10) different operation sizes. Conditions were created for each possible combination of Prototype or Prolog-based rule engine and JVM or RPC reasoning communications. ARTUE was tested at increments of ten (10) items with between thirty (30) and one hundred and twenty (120) cargo items introduced per phase to visualize the speedup generated by these improvements.

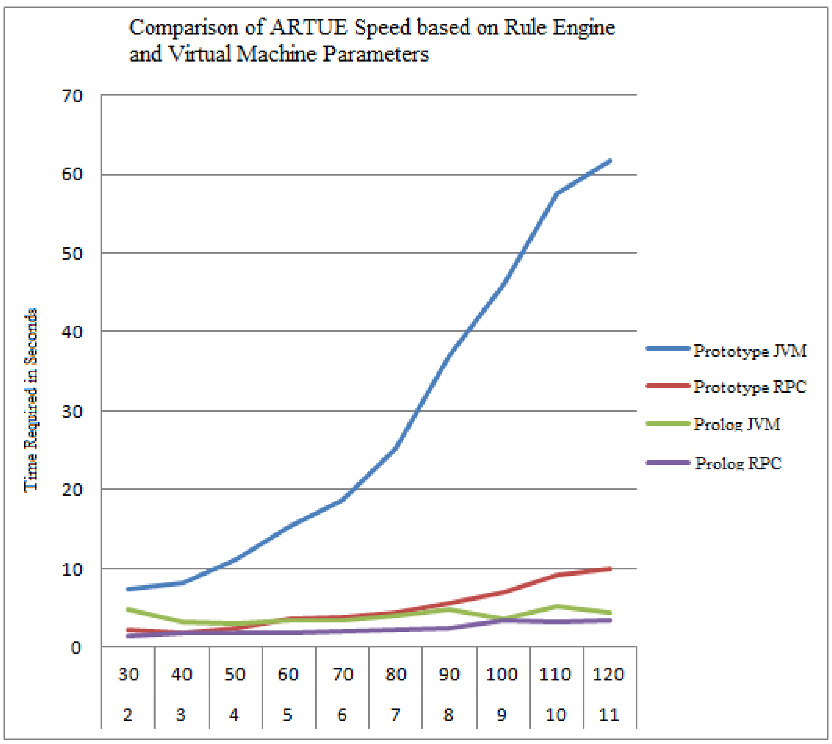

Figure 2: ARTUE Performance Results

Faster Rule Engine

To speed up rule firing, a number of third party rule engine solutions were investigated for which speed comparisons had already been conducted. Interface code was created to re-use an existing solution, named jTrolog, which is known to run quickly on the Java Virtual Machine.

Experimentation showed that use of jTrolog significantly improves performance over the prototype rule engine as the number of items in a plan grows, avoiding an exponential slowdown caused by poor prototype implementation.

Remote Procedure Call Server

The NRL ARTUE engine was designed to support a single use case in which all reasoning was performed in-process on top of a Java virtual machine, despite the implementation of reasoning facilities in the language Lisp. Translations between Java and Lisp queries proved time-consuming as operations were scaled up in support of R2D2. This prompted design of a faster alternative wherein a separate server process, running on the native machine rather than a Java virtual machine, is used to execution the reasoning code. Other Java services can then connect to the reasoning process as clients using a standard Remote Procedure Call (RPC) interface. This interface is available as needed. Experiments shown in Figure 2 recorded up to a five (5) fold performance increase when using the new design.

Asynchronous Multiple Access

While previous uses of the NRL ARTUE reasoning engine required no more than one simultaneous reasoning operation, R2D2 requirements prompted need to support parallelism. Multiple R2D2 users at different locations may have different queries to execute in ARTUE requiring need to serve them simultaneously without significant delay. Therefore, a session management component was introduced into the new ARTUE RPC server that allows reasoning about two separate queries to proceed simultaneously in parallel sessions. This improves both response time and turnaround time on client requests to the ARTUE Reasoning Engine.

Attachment 2: Non-Optimal Stacking Alerts

In response to questions regarding the applicability of R2D2 technology to container yard stacking problems, investigatory design and development was performed on ARTUE rules for producing Non-optimal Stacking alerts. This alert is generated when an item *A* is stacked underneath an item *B* and item *A* is expected to move before item *B* in an upcoming phase. The alert offers an alternate stack order for item *A* and all items stacked above it.

The following Non-Optimal Stacking Scenario illustrates this concept by showing a potential stacking problem and how R2D2 is expected to respond.

Scenario Movements:

Phase 0:

1. Items A-H are stacked aboard a ship in reverse order, in 3 stacks, prior to offloading.

Phase 1:

1. Items B and A are moved to stack A1-S1 in area A1.
2. Items E and F are moved to stack A1-S2 in area A1.
3. Items C and D are moved to stack A1-S3 in area A1.
4. Items G and H stay on the ship USS1

Phase 2:

1. Items B, D, and F are moved to stack A2-S1 in area A2.
2. Item E is expected in stack A2-S1 in area A2 but in the real world it is not moved from area A1.

During Phase 2, R2D2 alerts users to the Non-Optimal Stack F-B in Area 2. This stack is non-optimal because B needs to move before item F (i.e., in Phase 3). ARTUE also alerts users to the missing item E when Phase 3 ends. Figure 3 illustrates positions of boxes in ship and yard areas, shown at multiple time points corresponding to the end of abstract "movement phases". Stacks are shown as vertically arranged series of red boxes, with red lines connecting vertical neighbors. Each stack is named as well as the area it is in. At the bottom of each stack, a black striped box indicates the ground. In the top right corner of some items, a small "e" indicates that the item was expected during the indicated phase, its absence indicates that no expectation existed. If an "a" is present in the bottom right, then the item was reported to be in the location shown at the end of the indicated phase.

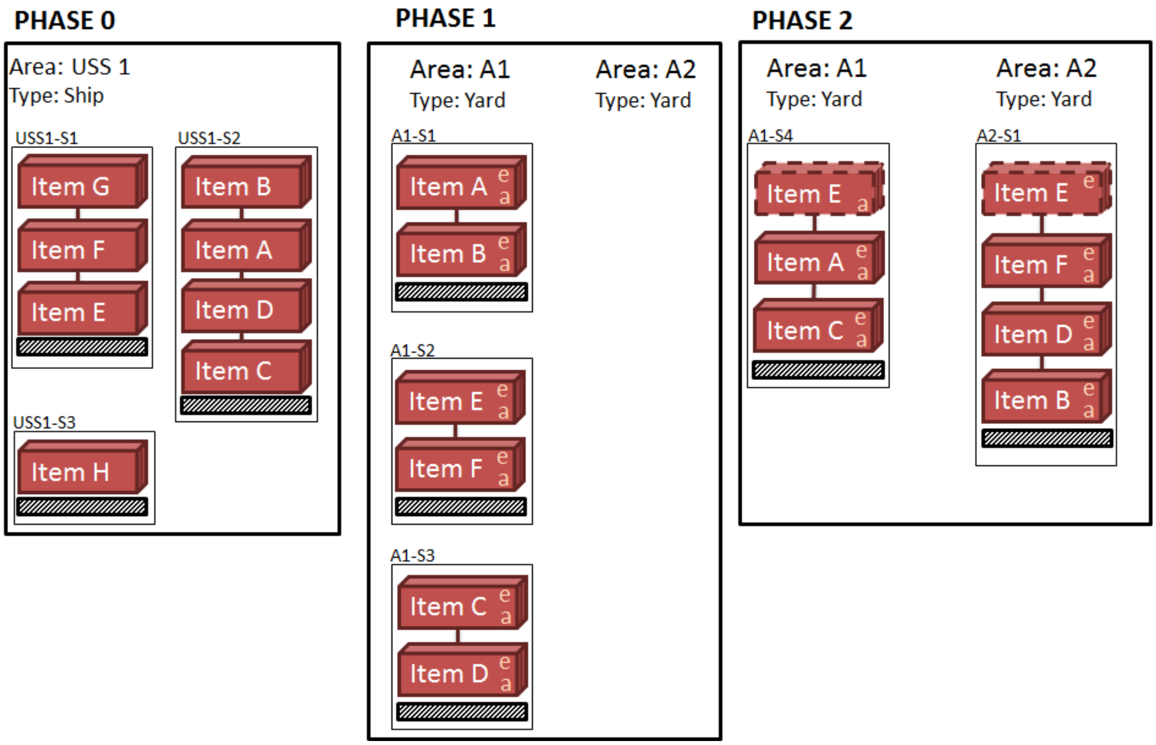

Figure 3: Non-Optimal Stacking Scenario Diagram

The alerts triggered by R2D2 during the Non-Optimal Stacking Scenario are shown by phase in Table 1.

Table 1: ARTUE-Generated Alerts for Non-Optimal Stacking Scenario

Phase 0	Phase 1	Phase 2
Non-Optimal Stacking Item F, E stack USS1-S1 (Optimal Stacking for stack USS1-S1: F-E for stack USS1-S3: G-H)	Non-Optimal Stacking Item B stack A1-S1 (Optimal stacking for stack A1-S1 A-C-E, for stack A1-S3 B-F-D)	Missing Item E (Area A2)
	Non-Optimal Stacking Item F stack A1-S2 (Optimal stacking for stack A1-S1 A-C-E, for stack A1-S3 B-F-D)	
	Non-Optimal Stacking Item D stack A1-S3 (Optimal stacking for stack A1-S1 A-C-E, for stack A1-S3 B-F-D)	